

Photosynthesis

Life in a sealed bottle

Try this one at home:

Take a transparent bottle with an air tight cap and a broad mouth. Put about 5 –10 cm depth of mud inside. Water the soil so it is well moistened but without water standing at the bottom of the container. Transplant a small plant into this soil, put the lid on to *seal it air tight*.

In the picture below, this has been done inside a fused bulb.



Now how long do you think the plant will survive? Click on the option that sounds appropriate to you.

- Minutes
- Hours
- Days
- Weeks

Can a plant survive being completely closed off from the external environment? Yes/No

Now, imagine yourself in an air tight container.



What are the things you might need to survive? Click on the ones that sound essential to you.

1. Air (specifically oxygen)
2. Water
3. Food
4. Provision for excretion/ejection
5. Cell Phone

In a closed container we would certainly die if any one of these were left out (maybe not a cell phone☺!).

It seems that the plant in the bottle should not survive for more than a few hours or maybe a day.

Surprise, surprise!

The picture here is of a plant that has been living in a sealed bottle for 40 years!!



Why do you think you cannot survive in a sealed bottle but a plant can? How are the needs of plants being met? Think a little carefully about this, since this shows a crucial difference between plants and animals. We will explore it as we go along.

Where does food come from?

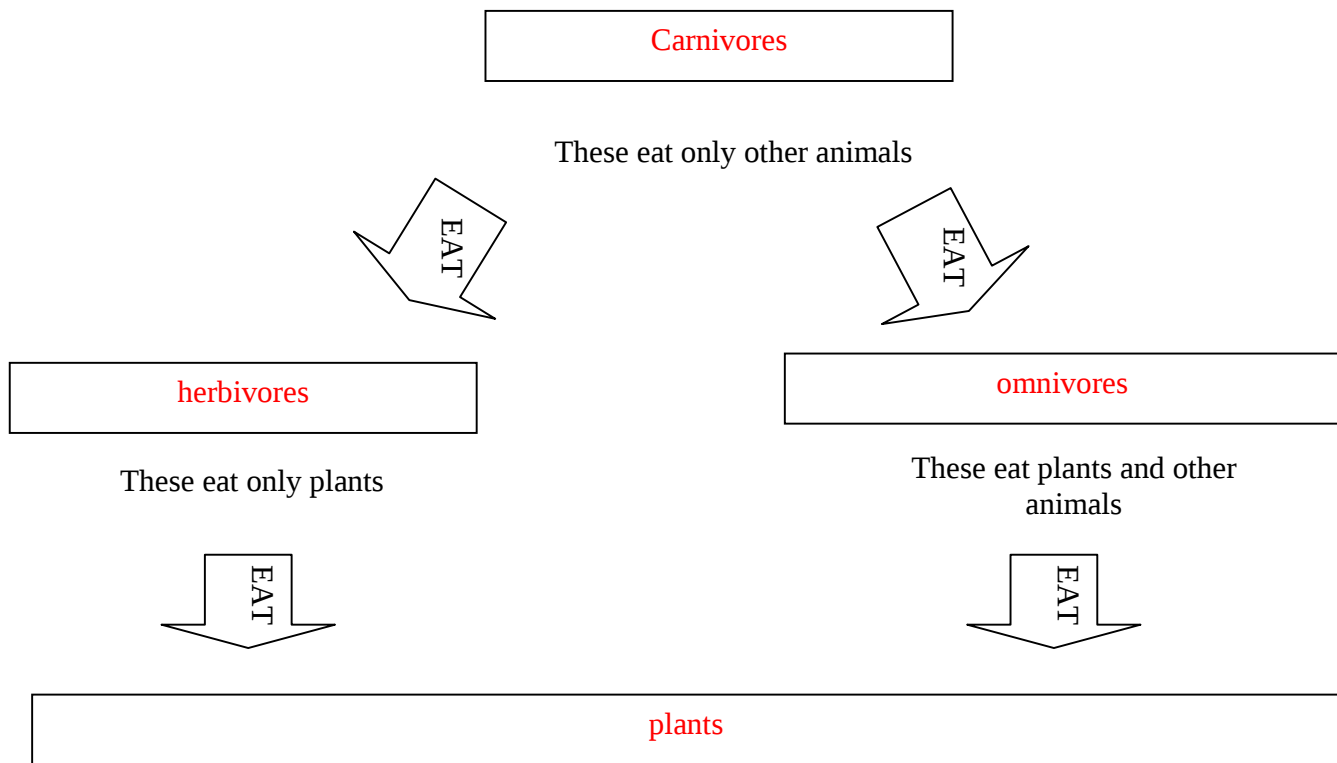
Recall the basic food chain by dragging and dropping the following 4 titles into the boxes:

Herbivores, Carnivores, Omnivores, Plants

Herbivores : “Are animals that eat only plants”

Carnivores: “Are animals that eat only other animals”

Omnivores: “Are animals that eat plants and animals”



From the food chain above we can see that herbivores and omnivores depend directly on plants for food. Carnivores indirectly depend on plants for food.



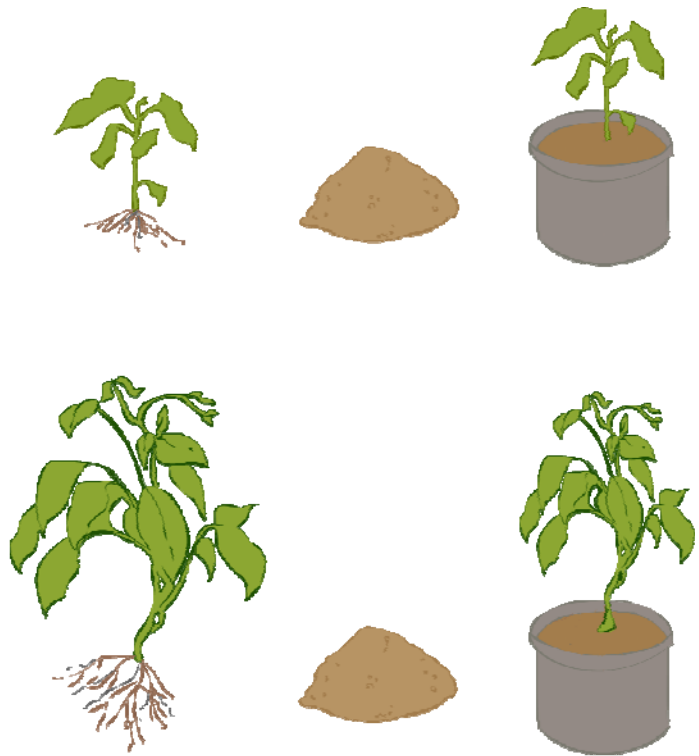
But what do plants depend on for food?

Let us look at how plants get their food and energy.

Plant gaining weight

In 17th century, a gentleman named Van Helmont did a simple experiment with plants and soil.

He took a large garden pot. He dried and weighed the soil he was going to put into it. He grew a willow tree in this pot. The only thing he added to the pot was distilled or rain water. Nothing else was allowed to fall on the soil in the pot.



After 5 years, he found that the tree had grown large and weighed about 74 kg. He dried the soil and weighed it again. The weight of the soil had only changed very slightly, about 60 grams.

Van Helmont used his experiment to conclude that the weight gained by the plant was **only because of addition of water.**

Let us examine what he concluded. Click on the option you agree with about the conclusions drawn from the previous experiment:

1. The gain in weight by the plant is due to the water added

Agree/Disagree

This might be correct. But is all the weight gain due to water alone? Helmont did not check this.

2. Water does not affect the weight of the growing plant.

Agree/Disagree

This would be an incorrect conclusion. Water was used, the plant gained weight and the plant can be checked to contain water.

3. The gain in weight is because of air and water

Agree/Disagree

This is what we would accept today. But in the experiment, there have been no observations regarding air.

4. Soil is not responsible for the increase in weight of the plant.

Agree/Disagree

60 grams of weight were lost by the soil. If we assume there are no errors, the soil may have contributed to a little weight gain.

5. Soil is not responsible for most of the weight gain by plants

Agree/Disagree

This is what we can reliably say from the experiment.

What was the crucial thing Van Helmont missed in his conclusion?

We can see that he completely ignored the role of air. But Helmont lived in a time when nothing was known about the weight or role of air. We remember Helmont for his spirit of careful experimentation.

At the time the experiment was conducted, it was still debated whether air was made of anything at all. There was no notion of Oxygen, Carbon Dioxide or even any form of particles of matter. For Van Helmont, the only matter that could add weight to the plant was either soil or water.

However, his experiment used a very important principle, the law of conservation of mass, which says that ‘matter can neither be created nor destroyed.’ It was clearly thought that if the tree was gaining mass, it must have come from some other mass.



Where does a plant get its food from?

In a bottle garden, a plant is given no food, yet it can survive for very long. So one important conclusion we can draw is from this observation is:

Plants must be having some way of making their own food!

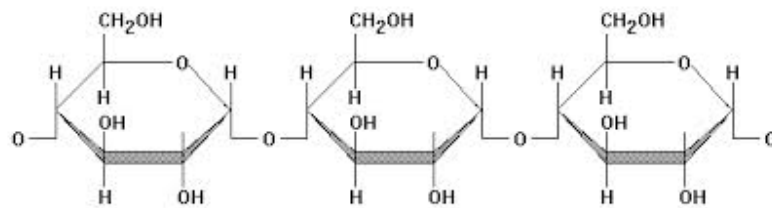
Living organisms need nutrients like proteins, fats and carbohydrates for their regular functioning. Plant would also need all these. So plant ‘food’ is also a category with many substances in it, but let us first begin with only **starch**, the simplest of them.

Starch is a substance composed of sugars. It is used by the plant as a way to store sugars. It is especially well suited for this purpose because it forms insoluble grains. If the plant stored sugars, it would have concentrated sugar syrup inside!

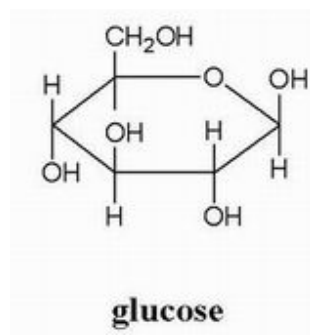


Let us recognize starch

Chemically, its molecule looks rather beautiful, like so many beetles in a row. Can you see three of them here?



And look at one molecule of a simple sugar



How do we test for starch?

We can test the presence of starch very easily inside substances. Get Tincture of Iodine or iodine solution or Potassium Iodide solution from any chemist. It is quite cheap.

Potato, cooked rice, wheat flour or any other substance can be tested for starch. The test gives better results with white or off-white substances, since we can observe colour changes easily.

Cut open a potato or the object selected for testing. Add a drop of Iodine solution and observe the change in colour. What do you observe?

With starch, Iodine turns from a brownish yellow to a blue-black colour.

Starch inside leaves

We can easily find starch inside plants. To see starch inside leaves or other green parts of a plant, we first need to remove the green colored substance called *chlorophyll*, since the dark green colour does not let us see the results of the test.

Choose a plant with variegated leaves (showing different colours) for this experiment.



How to remove chlorophyll before starch test?

Materials needed:

1. A beaker or vessel with tap water.
2. A test tube /syringe, vial or any narrow container that can be placed in the beaker/vessel.
3. Methanol/spirit (available as thinner for wood polish at hardware stores or as spirit at a chemist).
4. A source of heat to heat the water.
5. Tongs to hold the tube with methanol in it.

Caution! Methanol is highly poisonous. It also burns easily with a flame that is often not visible during the daytime. If methanol catches fire on someone's hand we may feel the burn without seeing the flame. It must therefore be handled carefully.

Set up the apparatus as shown in the figure. Turn on the flame. Before the water in the water bath boils, the methanol will begin to bubble (this is because methanol has a boiling point of just 65 degrees C). At this point you can reduce the flame to prevent methanol from spilling over.

The chlorophyll in the leaf will start going into methanol. You will see the leaf turn pale in colour while the methanol turns green. 2 to 5 minutes of boiling in methanol should make the leaf lose all green colour.

Now you can test the leaf for starch. Take the leaf out onto a slide/tile/plate and put 1-2 drops of tincture of iodine on the leaf. Where do you get the blue-black colour showing presence of starch?



Observe which parts of the leaves don't get this colour. If some portions appear too dark with blue-black colour, it shows the presence of a lot of starch.

Why do we see starch only in green parts of the leaves? Can you guess the reason?

These parts are showing presence of food. So perhaps the green colour has something to do with the plant's food production.

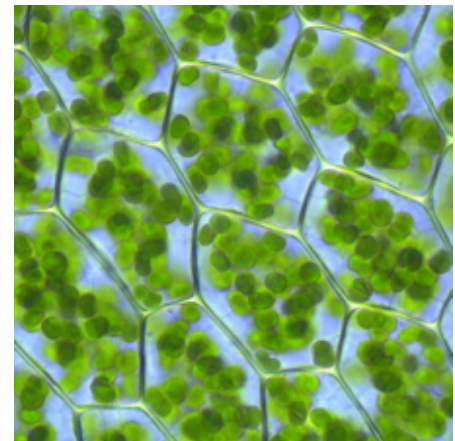
Let us explore this further.

Presence of Chlorophyll



Look at these plant cells under a microscope. Do you see lots of green particles?

The green colour in these particles is due to chlorophyll, a green pigment (a substance which gives colour to some material). A substance appears of a particular colour when *it reflects that colour*, and that colour of light enters our eyes. So chlorophyll must be reflecting green colour and absorbing other colours (like red and blue) from sunlight.



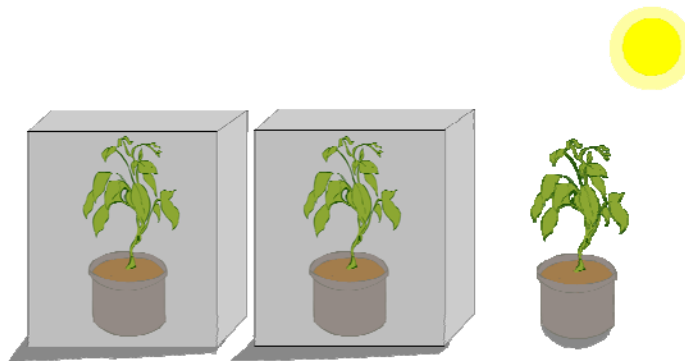
Many years of carefully study showed scientists that light absorbed by chlorophyll is *used as a source of energy* by the plant. *The plant can actually manufacture starch (food) in its leaves upon absorption of this energy.*

An experiment

Can we see any difference in the amount of starch present if we deprive plants of sunlight?

Let's do an experiment to test this. Select 3 similar leafy plants in pots, A, B and C. Water

them. Cover plants A and B with boxes to make sure they get no light. Plant C is left uncovered.



Keep them like this for 2 days. After this period, do you observe any change in each?

You will see that plants A & B are *much lighter in colour* as compared to C.

Guess what is causing this change in colour? Click on the options that seem correct to you:

- i. Lack of water

This cannot be correct since the plant C is still the original dark colour.

- ii. Lack of Light

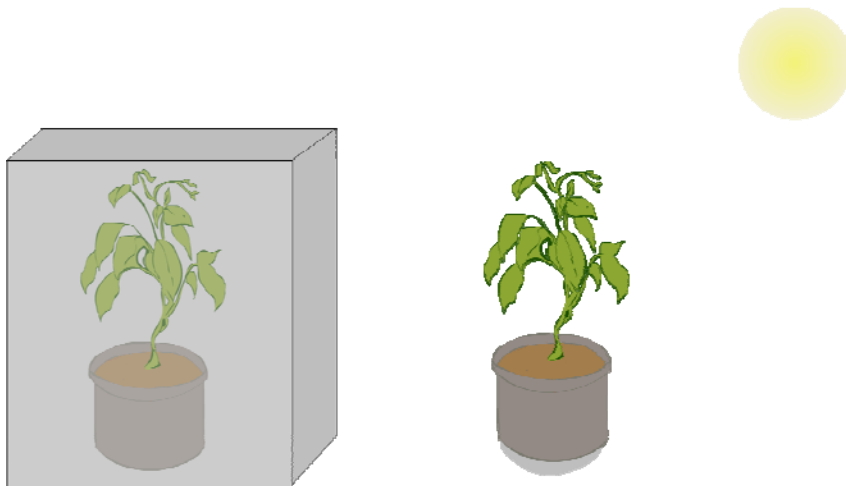
This seems correct since A and B have been kept away from light for 2 days.

- iii. Lack of Air

This cannot be correct since there was air inside the boxes.

Now let us proceed with the light coloured plants A and B.

Uncover plant A but keep plant B still covered. Leave them for about 1 hour in sunlight.



Now take a leaf from each plant and boil them separately in methanol to remove all the chlorophyll. Now test them for starch. What do you observe?



We see that the leaf of A, exposed to sunlight has **more starch grains** than B, which was covered!!

What can we conclude from this experiment? Write your conclusion in the box below.

It seems the presence of sunlight causes the amount of starch present in leaves to increase.

Why did we cover both plants for 2 days?

We needed to see the effect of sunlight on amount of starch present. But the plants could be having a lot of previously stored starch. So we reduced stored starch by depriving them of sunlight for two days.

Why did we not cover just one plant?

To compare the difference in starch because of difference exposure to sunlight.

Why did we keep a third plant C uncovered?

We did it to show the clear difference in the colour of leaves if plants are left in the dark.

If you do this experiment with the leaf from a normally growing plant, there is so much starch that it is often hard to observe things under the microscope when the leaf is stained with Iodine.

This experiment clearly shows that *placing plants in the dark causes them to lose starch*. Also, after this, the presence of sunlight causes the amount of starch present in leaves to increase, as we saw in plant A.

Creating food with the help of light-Photosynthesis

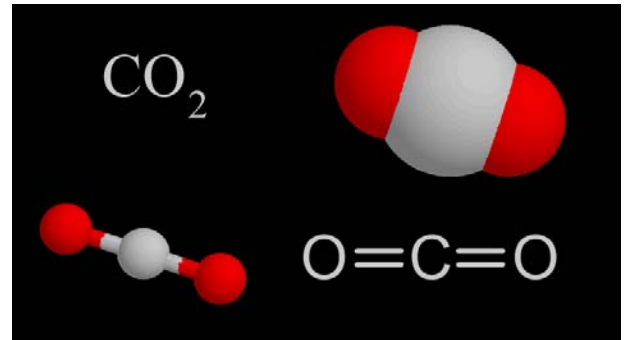
Plants are capable of creating their own food, which is simple sugar, by using light energy for combination of carbon dioxide (from air) and water. This process is called photosynthesis.

Photosynthesis = **photo** (=light) + **synthesis** (=a combination of two or more substances to form something new)

This is a capacity only plants, algae and some bacteria have. Hence plants are the basic food factories on earth!

The role of Carbon Dioxide in photosynthesis

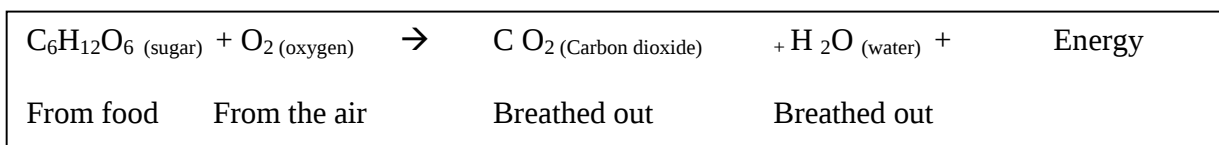
Carbon Dioxide is a gas found in small amounts in air. It is a molecule made up of 1 carbon atom and two oxygen atoms. It is formed when something containing carbon is burned in oxygen (for example, coal).



Inside our bodies, carbon compounds coming from food are burned slowly without a flame to produce carbon dioxide and energy.

Carbon compounds + oxygen = Carbon dioxide + water + energy

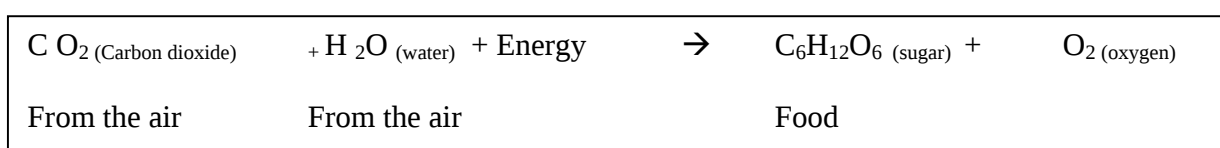
In chemical terms:



Think of *reversing this process*. Can carbon dioxide and energy be used to produce carbon compounds? This is what plants do, through photosynthesis!

Carbon dioxide + water + energy = Carbon compounds + oxygen

In chemical terms





This is exactly what plants do!! This is the chemical process of ***photosynthesis***. This was understood by humanity after centuries of experimentation!

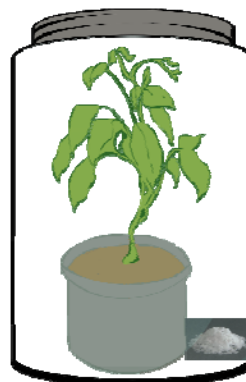
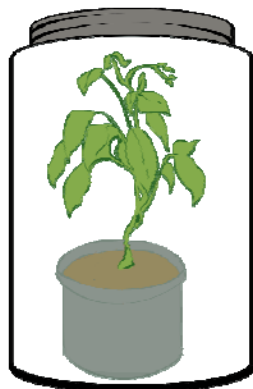
Also notice that the *photosynthesis reaction releases oxygen*. This is the single reason how oxygen comes back into the environment, though it is being used up constantly by all organisms (including plants) for respiration and other chemical reactions like combustion.

Testing for the role of Carbon Dioxide

Can we check for the role of CO₂ in photosynthesis?

Let us revisit the previous experiment of the plants A and B. Keep them again in the dark for 2 days.

We now change the steps slightly to see the need for Carbon Dioxide in photosynthesis. We now cover the plants A and B with transparent jars. Since sunlight can reach the plants, photosynthesis can continue.



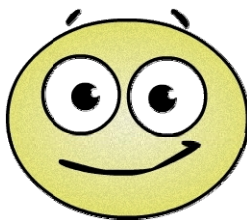
In jar B we also put a little bit of Potassium Hydroxide (KOH) inside, which can absorb carbon dioxide. We now place both jars in the sunlight. After two hours take out a leaf from each plant A and B and test for starch.

What do we see – Leaf from which plant, A or B, had starch ?

In this experiment we find that even though the plant B gets sunlight, it does not produce any new starch grains.



This demonstrates that CO₂ is necessary for photosynthesis.



This capacity to make their own food has given plants the name **autotrophs**; 'Auto' meaning self and 'trophe' meaning nutrition.

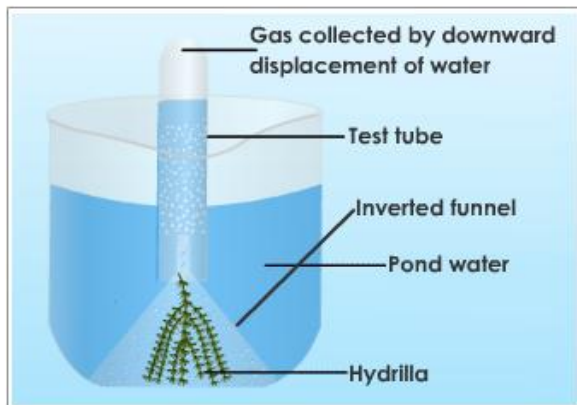
Those that cannot make their own food are called **heterotrophs**. Which are these?



We animals, of course!

Do plants give us oxygen?

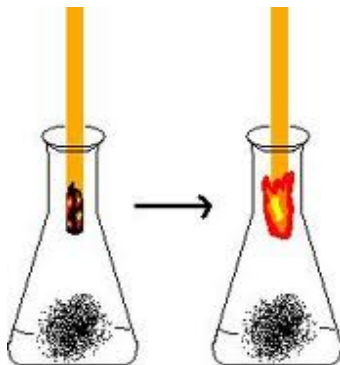
We can use an experiment to show how photosynthesis gives out oxygen.



Buy a piece of hydrilla from an aquarium store nearby. You may also use green algae or aquatic plants from a pond nearby, but the speed of the experiment may vary.

Using a beaker, a funnel and a test tube, set up the experiment as shown. Place this setup in the sunlight and observe. Bubbles are seen

arising from the plant and collecting in the test tube. It can take anything between 30 minutes to 5-6 hours to fill the tube. Once the tube is filled we can check how the gas collected affects a glowing splint of wood. If the gas is pure Carbon Dioxide, the splinter should go off immediately. If it is oxygen, the splinter should catch fire.



We find that the splinter catches fire, which suggests that Oxygen is produced.

Hydrilla and Vallisneria (the plants used in this experiment) are commonly available at aquarium stores because they are put in fish tanks. Guess why they are put in fish tanks! Check on the options that seem correct to you.

A) For food

Hydrilla is not mainly food for aquarium fish.

B) For decoration

This is not the real reason.

C) These plants give oxygen to the fish.

Plants simply release oxygen in water, without any possible purpose or use.

D) The fish take oxygen from plants.

Fish take oxygen from water, whichever source it comes from.

E) These plants release oxygen which is used by fish.

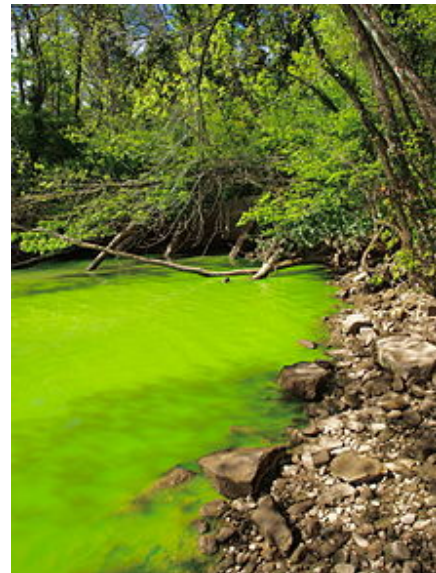
This is an accurate statement, and the reason why we put these plants in the tanks.

Plants during day and night

Let us see an interesting case of plants making and using oxygen differently during day and night.

When fertilizers and manure from farming enter still water bodies, this causes a great increase in the amount of algae (plants) growing in it. This is called *eutrophication*. We often see this as green water, as shown in the picture.

In such a pond we will find that oxygen levels rise very sharply in the daytime because of photosynthesis. At night, in the absence of sunlight, photosynthesis will stop.



What do you expect will happen to oxygen levels? Click the option you will choose.

A) In the absence of light, oxygen production will stop. The heterotrophs (animals and other non photosynthetic organisms) will use oxygen, causing levels to drop.

Animals will certainly use oxygen in the night certainly, but plants will also use oxygen at night. Check other options.

B) The oxygen levels will be low because oxygen is a gas and will escape as bubbles.

Some Oxygen does leave the water as bubbles but water is able to hold back much oxygen dissolved between water molecules. Water organisms use this oxygen.

C) All the large number of algae (Plants) and heterotrophs will use the oxygen by night causing a sharp drop in oxygen levels.

This is correct. After sunset, autotrophs and heterotrophs both use oxygen causing dissolved oxygen levels to drop fast.

In such ponds, organisms that need high levels of oxygen may suffocate and die because of low levels of oxygen. When they die, bacteria feed on them and multiply. This uses up more oxygen. Even more deaths occur till many organisms of the original pond are wiped out.

As we can see, at night, plants use oxygen to burn food (for respiration). Since they cannot use CO₂ for photosynthesis at night, they release it into the air. So it is incorrect to say that plants give us only oxygen.

Trees at night

Many people feel that it is unsafe to sleep under a tree at night because trees might suffocate us with the CO₂ they give out at night. This is inaccurate because:

A) Oxygen moves freely in the air to places where oxygen is in lower concentration

This is correct. Check other options too.

B) If a single tree could kill us, then there should be no animals or human beings living in forests.

This is correct. Diffusion (the spreading of gas) is a powerful process. Even in a closed room, enough oxygen diffuses in and CO_2 diffuses out to keep people respiring. Check other options too.

C) If a tree can kill us in the open, then sleeping in a closed room with your whole family should kill everybody.

A respiring tree cannot kill us. A campfire gives out much more carbon dioxide, but does not kill or harm people sitting around it in the open.

Daytime respiration in plants



When plants are doing photosynthesis, are they also respiring? This is very confusing! Which gases are going in and out?

Plants also respire during the day. Hence they consume oxygen and release CO_2 as well. This cannot be demonstrated by any simple experiment because the CO_2 is used in photosynthesis before it is released.

In the Hydrilla experiment, we collected O₂ in the tube. Why wasn't there any CO₂ in our tube? This can be explained because:

A) We cannot say that there wasn't any CO₂ in the tube.

This is accurate. Our test of the glowing splint only proves the presence of a high amount of Oxygen. There may or may not be CO₂. Please review the remaining options.

B) When the plant gives out CO₂, it is quickly reused through photosynthesis to form O₂.

This is probably correct and should be thought of along with the other two options as well.

C) The rate of O₂ production is much higher than CO₂ production because the plant is trapping more energy than it is using.

This is correct and should be thought of along with the other two options as well.

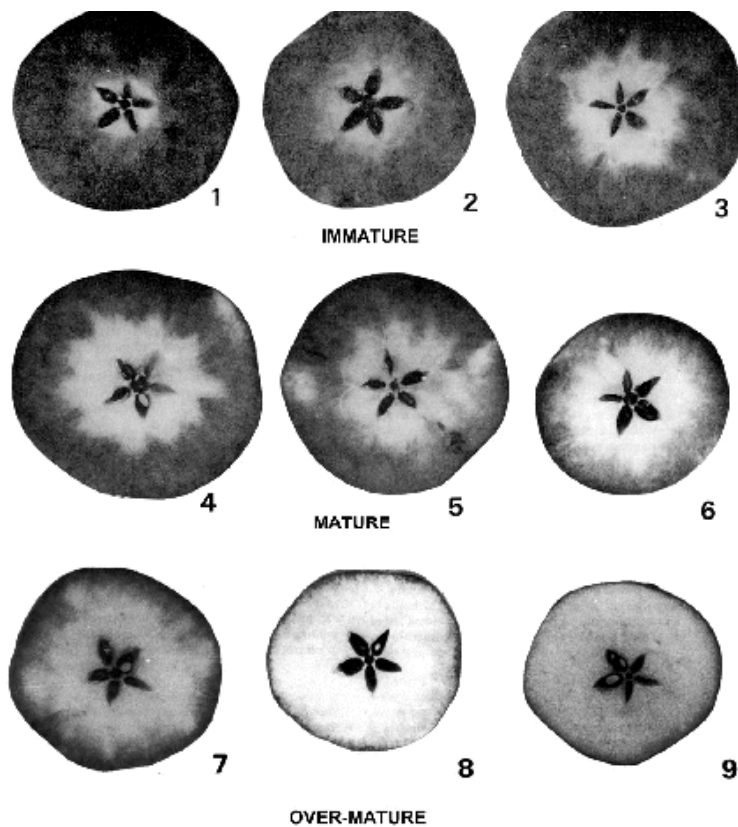
How can food come out of gas, water and light?

We often have difficulty imagining a plant gaining weight from gas, water and sunlight. This is mostly because we don't think of gases as matter, having weight.

But it is possible to observe a reverse process of plants losing weight by giving out gases. We can see this through the process of respiration in apples.

After an apple is plucked from the tree, it continues ripening. First it loses its green colour, slowly becoming yellow and red. At this point it is full of starch. In a few days, the red colour gets deeper and a sweet smell appears. The apple is juicy and sweet at this stage.

Slowly the apple turns dry or pasty, sweet and almost potato like in texture. In this phase, apples have much less weight than before.



Looking at the results of starch tests on apples, we see that ripe apples show less starch than raw ones. This is because (Choose the appropriate option):

- A) Raw apples are green and still producing starch by photosynthesis
- B) Ripe apples lose their starch
- C) Apples continue to live and respire even after they are plucked. This means they are consuming their food (starch) stored inside them.

C is correct. The respiring apple loses weight as it converts starch into CO₂ and H₂O.

We normally think that loss in weight is because of drying. This is correct, but the apple is still living. It is losing weight through respiration as well. The apple is consuming its own stored food for living! Ripe apples keep losing weight even when kept covered in plastic with small openings.

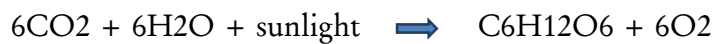
In respiration:

Starch is converted to sugar.

Sugar $\Rightarrow$ CO₂ and H₂O



In photosynthesis,



CO₂ and H₂O combine to make sugar.

Sugar is then converted to starch.

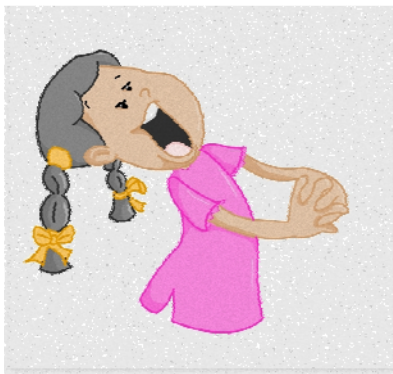
Photosynthesis uses light energy of the sun and stores it as chemical energy in starch. When starch is broken down by respiration, it does not release light energy. It produces chemical energy.

When we (and other heterotrophs) eat starch, sugar or other products of photosynthesis by plants, we burn them with respiration, and use the chemical energy produced to run our bodies.

Why do plants need soil?

We saw that in the presence of sunlight, carbon dioxide and water, plants are able to make starch. Making starch as food is a way for plants to store energy.

But, the mystery is not even partly solved yet! There are many important questions left, like:



Do plants need no other food other than starch?

Why do we add plant nutrients to soil?



The first question helps answer the second. Sugar and starch are forms in which a plant stores the energy trapped by it. Sugar can be used to make many other molecules like fats and oils.

However, plants need thousands of different molecules that cannot be produced by photosynthesis alone.

See the table below. Tick the checkboxes alongside the nutrients that can be supplied through glucose $\text{C}_6\text{H}_{12}\text{O}_6$ (sugar)

	Nutrient name	Symbol
	Macronutrients	
	Carbon	C
	Hydrogen	H
	Oxygen	O
	Nitrogen	N
	Phosphorous	P
	Potassium	K
	Calcium	Ca
	Iron	Fe
	Magnesium	Mg
	Sulphur	S

Where do you think a plant would get the remaining nutrients from?

The answer to this question is: *From the soil.*

Given below are some commonly used fertilizers. Which nutrients are being supplied to the plant through these in the soil? Which nutrient the plant cannot get from simple sugar?

Urea NH_2CONH_2

N or Nitrogen

Potash K_2O

K or potassium

Superphosphate $\text{Ca}_2\text{H}_2(\text{PO}_4)_2$

Ca or Calcium, P or phosphorus

Thinking about the garden in the bottle again

Why do plants need soil in the first place? What do you think? Write your answer in the box below.

Soil can be primarily for providing support, but may also supply some nutrients. But since many plants survive without soil (can you think of any?), soil is not essential for survival.

Where do our bottle gardens get their water from after they have been watered the first time?

The same water that was given in the beginning is recycled in the bottle, as the plant loses it through evaporation from its leaves, and then the same water condenses, drops and goes back to the soil, in a simple way like the water cycle of the earth.

Where do plants get their food from?

Yes, as we have seen, they make their essential food.

Where are they getting the essential oxygen from?

They are getting it as a product of photosynthesis done by the plant itself, since the plant is receiving sunlight.

Image credits:

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